Charles Darwin University

Final Examination

Family Name	
Given Name/s	
Student Number	
Teaching Period	Semester 1, 2018

ENG341 – Separation Process Principles	DURATION	
	Reading Time:	10 minutes
	Writing Time:	180 minutes

INSTRUCTIONS TO CANDIDATES

- The paper has only one section. Answer All Questions.
- All calculations to be performed in the answer booklet issued
- Please refer to the Appendix at the end of the question for necessary equations and diagram required.
- Please attach Equilibrium diagrams supplied in the Appendix to your answer booklets where applicable.

EXAM CONDITIONS

<u>You may begin writing from the commencement of the examination session.</u> The reading time indicated above is provided as a guide only.

This is a CLOSED BOOK examination

Any non-programmable calculator is permitted

No handwritten notes are permitted

No dictionaries are permitted

ADDITIONAL AUTHORISED MATERIALS	EXAMINATION MATERIALS TO BE SUPPLIED
No additional printed material is permitted	1 x 20 Page Book 1 x 8 Page Book 2 x Scrap Paper Graph paper

THIS EXAMINATION IS PRINTED DOUBLE-SIDED.

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Total Number of Marks: 100

All questions should be answered in the Answer Booklet provided.
Please Note that All Questions are to be answered.

Marks for each question are indicated. Suggested time allocation: 180 mins

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Question 1

(a) A distillation column using an open steam configuration is separating methanol and water. The bottom product is to contain 95 mol % water. The operating lines of the top section and the feed are shown in **Fig. 1 in Appendix I**. Based on the given figure, calculate the following:

(b)

i. What is the reflux ratio at which the column is being operated?

(Marks: 02)

ii. Write down the equation of the operating lines for the rectification and stripping sections respectively for the given separation.

(Marks: 05)

iii. Determine the number of theoretical plates required to perform the given separation and indicate the location of optimum feed stage.

(Marks: 04)

(c) The flow rates of three components in a feed to a distillation column are given on the **Table. 1**. The feed is saturated liquid. The distribution coefficients, k, at a temperature 90^{o}C are given and you can assume that the relative volatilities are fairly constant. It is expected to remove 99% of C_2 present in the feed in the top product and 99% of C_3 present in the feed in the bottom product.

Table. 1: Given data for Question.1 (b)

Components	C_1	C_2	C_3
Feed flow rate, kmpl/h	10	20	30
Distribution coefficient, k	5	2.5	0.5

i. What is the minimum number of trays required for the separation?

(Marks: 04)

ii. What is the minimum reflux ratio?

(Marks: 06)

iii. How many number of plates do we require if we were to operate the column at $L/D=1.1(L/D)_{min.}$ Gilliland correlation is available in **Fig. 2 in Appendix I**.

(Marks: 04)

Question 2

(a) A vent gas in your chemical plant is 15 wt.% Z; the rest is air. The local pollution authorities feel that Z is a minor pollutant and require a maximum concentration of 4 wt.%. You have decided to build an absorption tower using water as absorbent. The inlet water is pure and at 30^{o}C. The operation is essentially isothermal. At 30^{o}C your laboratory has found that the equilibrium data can be approximated by y=0.5x (where y and x are weight fractions of Z in vapor and liquid, respectively). Separate Graph paper is supplied to you for solving this problem.

i. Find the minimum ratio of water to air, (L/G)min.

(Marks: 05)

ii. With L/G = 1.22 (L/G)min, find the total number of equilibrium stages and the outlet liquid concentration.

(Marks: 05)

(b) Carbon dioxide is to be stripped from a liquid stream using air. The inlet liquid flowing at 2000 kg/hr contains 20 wt.% CO_2. The exit liquid is to contain less than 0.5 wt.% CO_2. Your company has a blower that supplies 100,000 kg/h of air. The company has four contacting stages and wants to try using a cross current configuration as shown below in **Fig. Q2** by equally distributing the air (which contains no CO_2) to the 4 stages. The equilibrium diagram for CO_2 stripping using air is available in **Fig. 3** in **Appendix II.**

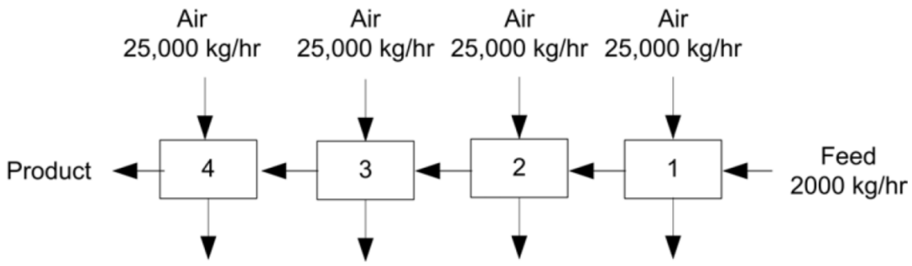


Figure. Q2: Cross flow absorber for CO2 absorption corresponding to **Question 2 (b)**

i. Write down the operating line equation for a stage.

(Marks: 03)

ii. Using the equilibrium curve given, plot the appropriate operating lines and calculate the composition of CO_2 in the exit stream and the composition of CO_2 in the air stream leaving stage 3.

(Marks: 08)

iii. Will this configuration meet the required exit concentration that is expected? If not, suggest an alternative configuration to get the required outcome with the help of simple schematic.

(Marks: 04)

Question 3

(a) Air containing 1.6 mol % SO_2 is scrubbed with pure water in a packed column of 1.5 m^2 cross sectional area and 3.5 m height packed with no. 2 plastic Intalox saddles, at a pressure of 1 atm. Total gas flow rate is 0.062 kmol/s, the liquid flow rate is 2.2 kmol/s, and the outlet gas SO_2 concentration is y = 0.004. Molar volume of gas at STP is 22.4L. At the column temperature, the equilibrium relationship is given in **Fig. 4 in Appendix III.**

i. What is the value of L/L_{min}?

(Marks: 04)

ii. Calculate overall number of (gas) transfer unit, N_{OG}

(Marks: 06)

iii. Determine overall height of (gas) transfer unit, H_{OG}

(Marks: 02)

iv. Calculate overall gas phase coefficient, $K_G a$

(Marks: 03)

(b) A sieve-plate distillation column is separating a feed that is 50 mole % n-hexane and 50 mole % n-heptane. Feed is a saturated liquid. Plate spacing is 24 in. Average column pressure is 1 atm. Distillate composition is xD = 0.999 (mole fraction n-hexane) and xB = 0.001. Feed rate is 1000 lbmol/h. Internal reflux ratio L/V = 0.8. The column has a total reboiler and a total condenser. Assume operating vapor velocity is 75% of the flooding velocity and fraction of the column cross-sectional area that is available for vapor flow rate is 0.90. Refer to **Fig. 5 in Appendix IV** for capacity factor for flooding of sieve trays. Additional information is given below:

Universal gas constant, R = 1.314 atm,ft^3/(K. lbmol)
Properties of Pure n-hexane:
Boiling point, T =69°C = 342K
Density of liquid, ρ_L = 41.12 lb/ft^3
Molecular weight, MW = 86.17
Surface tension, σ = 13.2 dynes /cm

i. Determine flooding velocity

(Marks: 06)

ii. Estimate required diameter at the top of the column. Diameter of the column can be expressed as

$$\text{Dia} = \sqrt{\frac{4VRT}{\pi \eta (3600) p (\text{fraction}) u_{\text{flood}}}}, \quad \text{ft}$$

Where, η = fraction of column cross sectional area available for vapor flow rate; V= vapor/gas flow rate; u_{flood} = flooding velocity.

(Marks: 04)

Question 4

1000 kg/h of a 45 wt % acetone-in-water solution is to be extracted at 25 ^{o}C in a continuous, countercurrent system with pure 1,1,2-trichloroethane to obtain a raffinate containing 10 wt% acetone. Two similar Right-angle equilibrium plots in Fig. 6 and Fig.7 are available in Appendix V. Using the right-angle plots:

(a) Determine the minimum flow rate of solvent.

(Marks: 10)

(b) Estimate the number of stages required for a solvent rate equal to 1.5 times minimum.

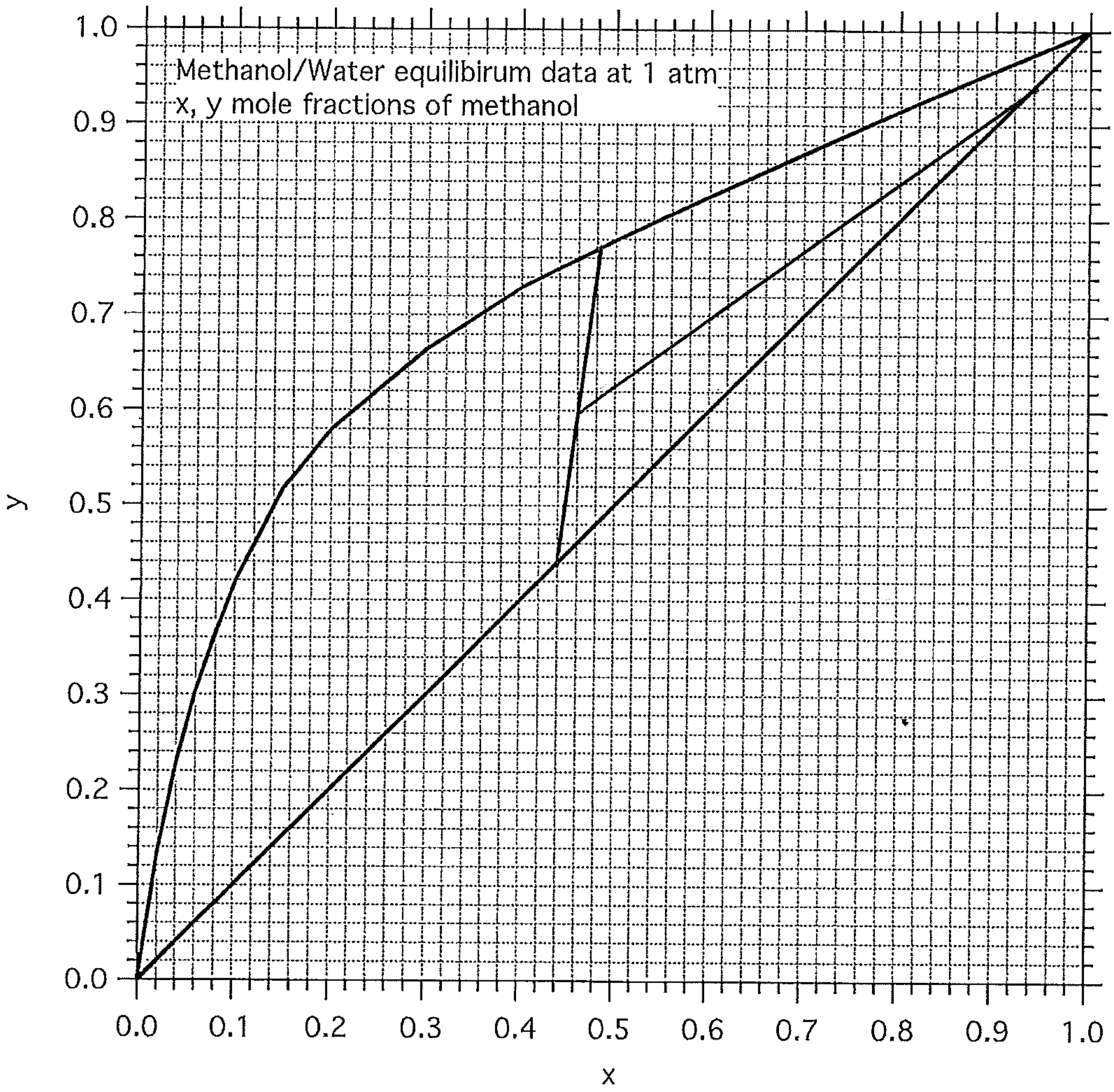
(Marks: 10)

(c) Find the flow rate and composition of each stream leaving each stage.

(Marks: 05)

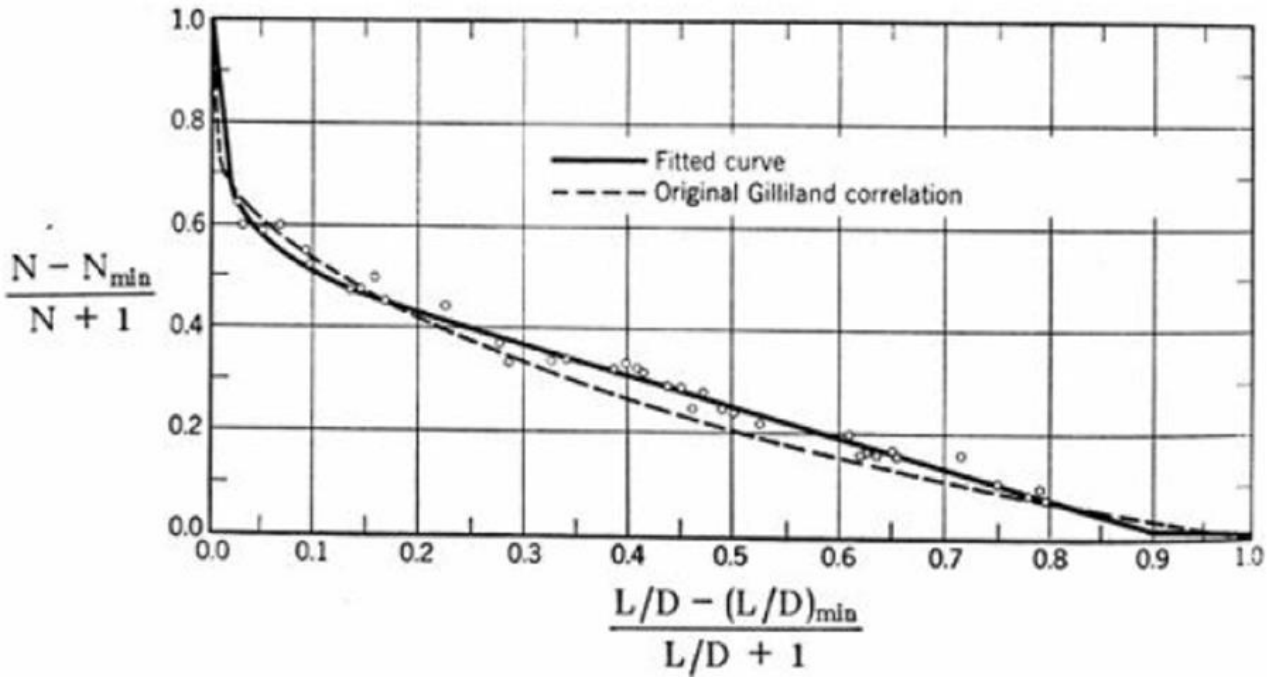
APPENDIX I

i. **Figure 1:** x-y diagram for methanol water system corresponding to **Question. 1 (a)**



APPENDIX I (continued)

ii. Figure 2: Gilliland correlation corresponding to Question. 1 (b)



iii. Fenske equation:

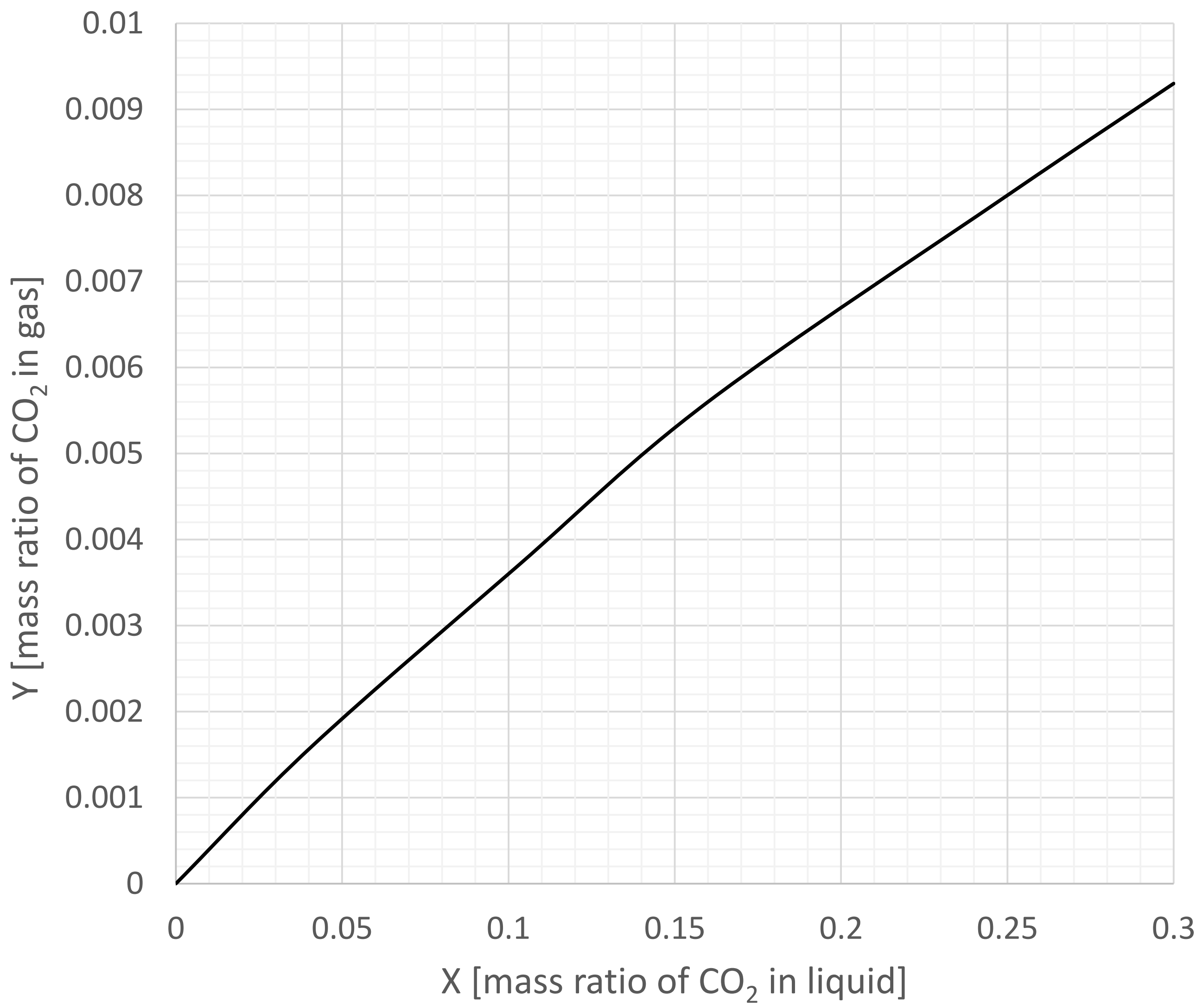
$$N_{min} = \frac{\ln\left[\left(\frac{x_A}{x_B}\right)_{dist} / \left(\frac{x_A}{x_B}\right)_R\right]}{\ln \alpha_{AB}}$$

iv. Underwood equation:

$$\Delta V_{feed} = V_{min} - \overline{V}_{min} = \sum_{i=1}^{c} \frac{\alpha_{i-ref} F z_i}{\alpha_{i-ref} - \phi}$$

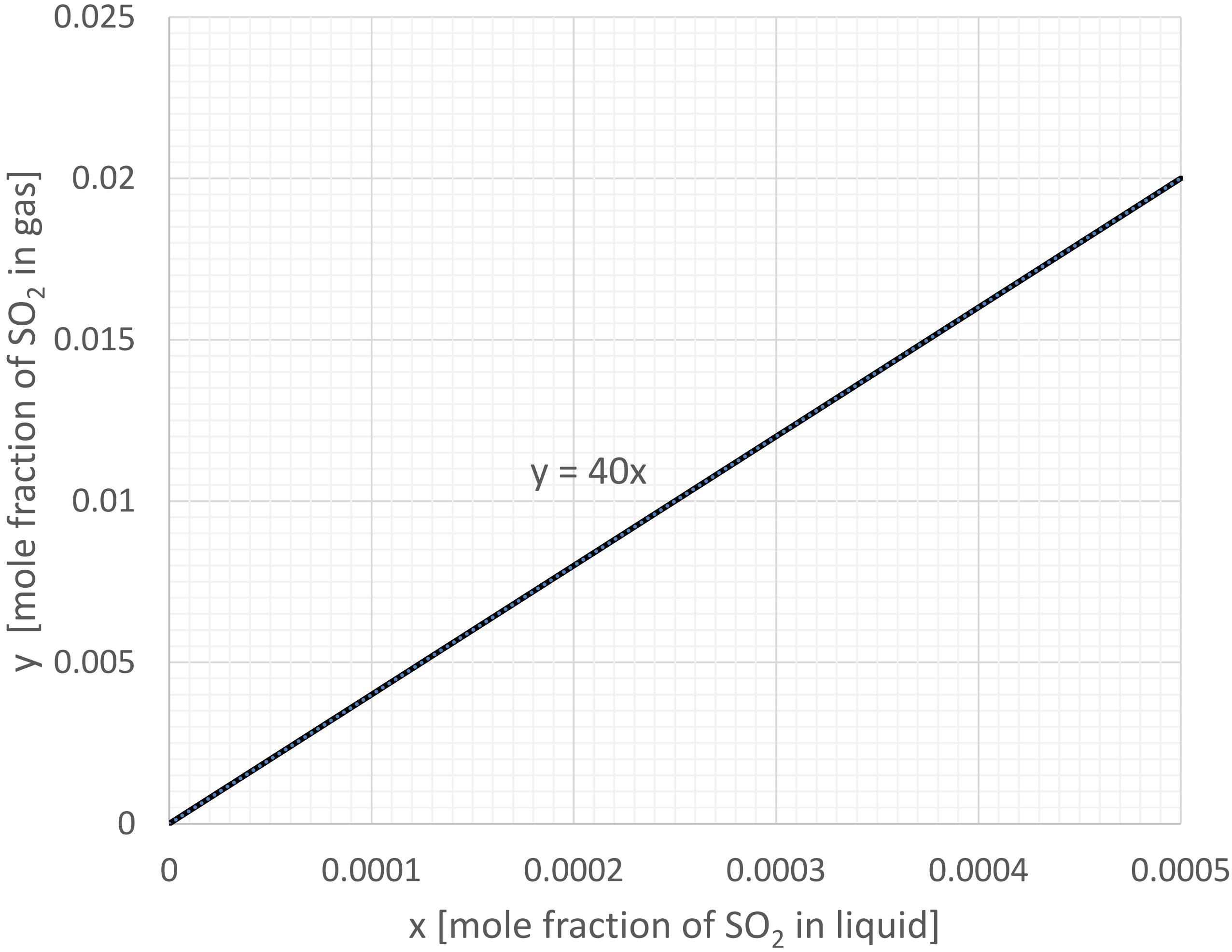
APPENDIX II

Figure 3: Equilibrium curve for CO_2 stripping using air corresponding to **Question. 2 (b). Take note of the axis.**



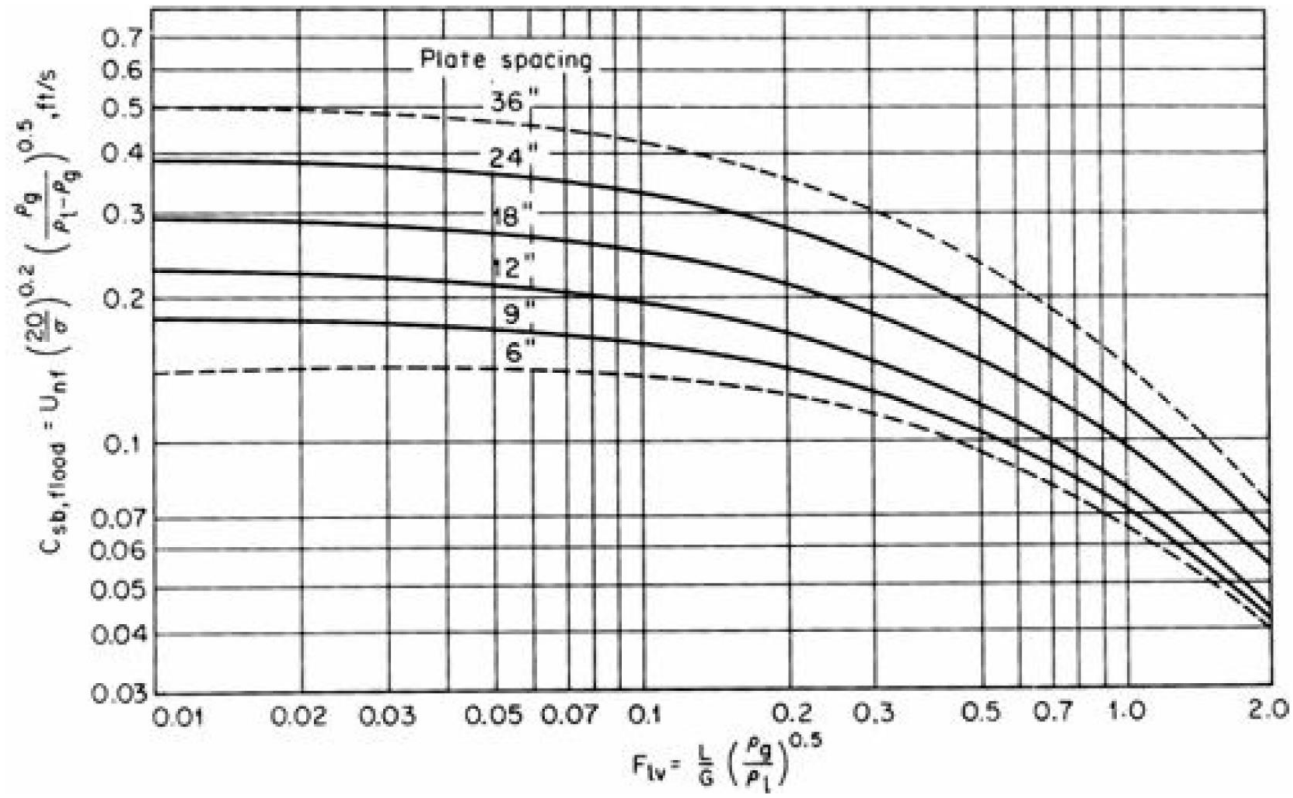
APPENDIX III

Figure 4: Equilibrium relation of SO_2 absorption using water corresponding to **Question. 3 (a). Take note of the axis.**



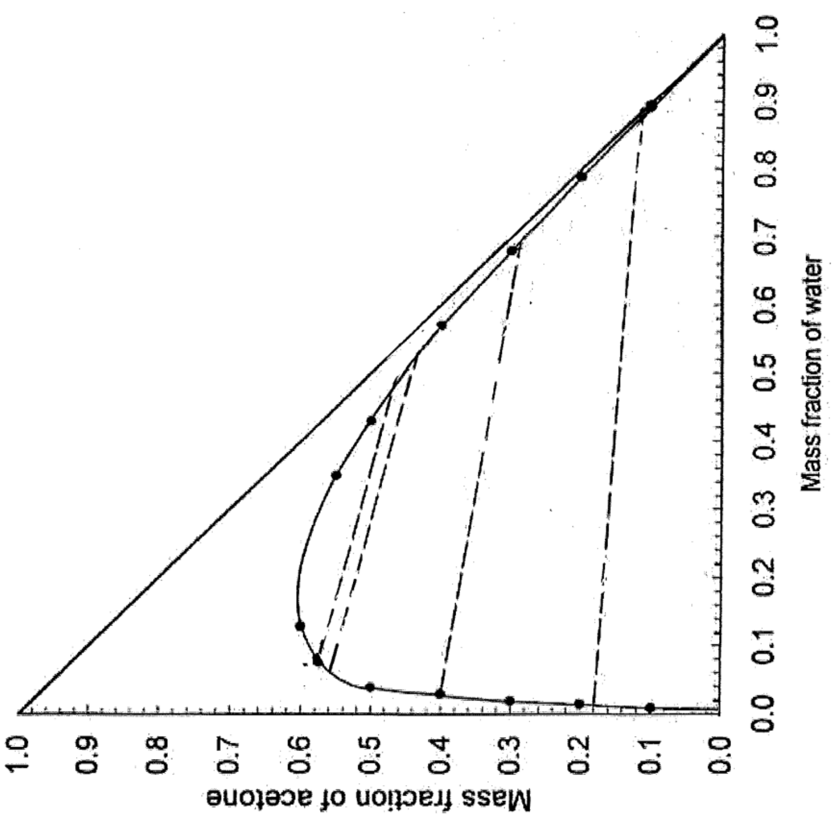
APPENDIX IV

Figure 5: Capacity factor for flooding of sieve trays corresponding to Question. 3 (b).
Where, $C_{sb,f}$ = capacity factor, F_{lv} = flow parameter, $U_{n,f}$ = flooding velocity , ρ = density, σ=surface tension, L= liquid flow rate and G= gas flow rate.



APPENDIX V

i. **Figure 6**: Right triangle plot for **Question 4(a)**



APPENDIX V (continued)

ii. **Figure 7**: Right triangle plot for **Question 4(b)**